

# Exploring Flavor Structure of SUSY Breaking from B Decays and the Unitarity Triangle<sup>a</sup>

TORU GOTO

*YITP, Kyoto University, Kyoto, 606-8502 Japan*

E-mail: goto@yukawa.kyoto-u.ac.jp

## ABSTRACT

We study effects of SUSY particles in the unitarity triangle analysis and the CP asymmetries in  $b \rightarrow s$  decays. We consider three different SUSY models, the minimal supergravity, SU(5) SUSY GUT with right-handed neutrinos, and MSSM with U(2) flavor symmetry, and show that the patterns and correlations of deviations from the standard model will be useful to discriminate the different SUSY models in future  $B$  experiments.

## 1. Introduction

Goals of  $B$  physics are not only to determine the Cabibbo-Kobayashi-Maskawa (CKM) matrix, but also to search for new sources of CP violation and flavor mixings. In the minimal supersymmetric standard model (MSSM), the squark mass matrices can be such sources. Since the squark mass matrices depend on the SUSY breaking mechanism,  $B$  physics can provide important information on the origin of the SUSY breaking.

In this work [1], we study the flavor signals in SUSY models with different flavor structures, namely, the minimal supergravity (mSUGRA), the SU(5) SUSY GUT with right-handed neutrinos, and the MSSM with U(2) flavor symmetry [2]. We consider two cases in the SU(5) SUSY GUT with  $\nu_R$ . One is “degenerate” case, where all the masses of right-handed neutrinos are the same, and the other is “non-degenerate” case, where the  $\nu_R$  mass matrix is not proportional to the unit matrix.

We focus on two subjects: the consistency test of the unitarity triangle and the CP asymmetries in  $b \rightarrow s$  decays. We calculate SUSY contributions to the  $B_d - \bar{B}_d$ ,  $B_s - \bar{B}_s$ , and  $K^0 - \bar{K}^0$  mixing amplitudes and show that the unitarity triangle analysis is useful to discriminate these models. As for the  $b \rightarrow s$  decays, we investigate the direct CP asymmetry in the inclusive  $b \rightarrow s\gamma$  decay [3] and the mixing-induced CP asymmetry in  $B_d \rightarrow \phi K_S$  [4] and  $B_d \rightarrow K_{CP}\gamma$  [5], where  $K_{CP}$  is a CP eigenstate with a strange quark. We show that the above models exhibit different pattern of deviations from the SM.

## 2. Unitarity Triangle

In the SM, the source of the flavor mixing and the CP violation is the CKM matrix only. Present knowledge of the parameters in the unitarity triangle  $\bar{\rho}$  and  $\bar{\eta}$ , which are defined as  $\bar{\rho} + i\bar{\eta} = -\frac{V_{ub}^* V_{ud}}{V_{cb}^* V_{cd}}$ , is obtained by combining the measured values of  $|V_{ub}|$ ,  $\sin 2\phi_1$  from the CP asymmetry in  $B_d \rightarrow J/\psi K_S$ ,  $\varepsilon_K$ ,  $\Delta m_{B_d}$  and the lower bound of  $\Delta m_{B_s}$ .

<sup>a</sup>Talk based on Ref. [1], given at the 12th International Conference on Supersymmetry and Unification of the Fundamental Interactions (SUSY04), June 17-23, 2004, in Epochal Tsukuba, Tsukuba, Japan.

In the future, we expect that  $\Delta m_{B_s}$  and  $\phi_3$  are measured precisely. At this stage, some mismatch among the observables might be found, which means an existence of new source of the flavor mixing and/or CP violation. We can obtain information about the flavor structure of the SUSY model from the pattern of the mismatch.

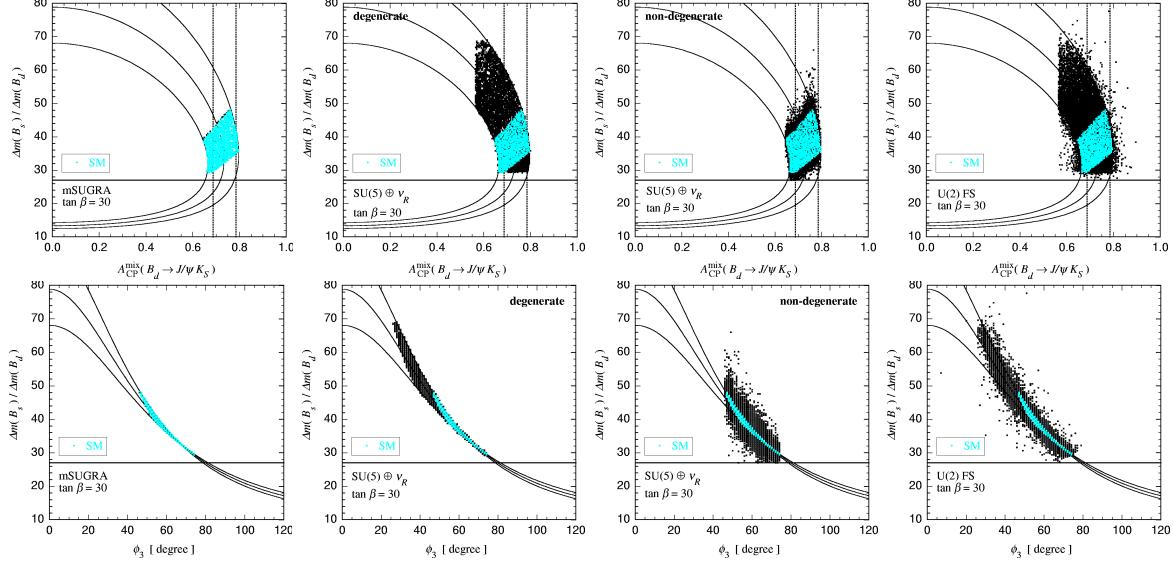


Figure 1:  $\Delta m_{B_s}/\Delta m_{B_d}$  versus  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow J/\psi K_S)$  (upper row) and  $\phi_3$  (lower row) in each model.

In Fig. 1, we show our numerical result on the correlation among  $\Delta m_{B_s}/\Delta m_{B_d}$ ,  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow J/\psi K_S)$  and  $\phi_3$ . Varying the free parameters in each model, we searched for allowed regions consistent with the present experimental constraints. In mSUGRA, possible deviations of all the three quantities are small. In the degenerate case of the SU(5) SUSY-GUT with  $\nu_R$ , SUSY contributions to the first and second generation mixing become large, so that  $\mu \rightarrow e\gamma$  and  $\varepsilon_K$  are enhanced. After imposing the experimental constraint on  $B(\mu \rightarrow e\gamma)$ , sizable SUSY contribution appears only in  $\varepsilon_K$ . This correction of  $\varepsilon_K$  leads to a change of the allowed region of  $\phi_3$  and eventually affects the possible region of  $\Delta m_{B_s}/\Delta m_{B_d}$ . In the non-degenerate case, the neutrino Yukawa coupling matrix is chosen such that  $\mu \rightarrow e\gamma$  is suppressed [6]. Then sizable contribution to  $\Delta m_{B_s}$  is possible. For the U(2) model, both patterns of deviation are possible.

### 3. CP Asymmetries in $b \rightarrow s$ Decay

The effective Lagrangian relevant for the  $b \rightarrow s$  decays is

$$\mathcal{L}_{\text{eff}} = C_{7L}\mathcal{O}_{7L} + C_{8L}\mathcal{O}_{8L} + (L \Leftrightarrow R) + (\text{four-quark}),$$

where  $\mathcal{O}_{7L} = \frac{e}{16\pi^2}m_b\bar{s}\sigma^{\mu\nu}b_RF_{\mu\nu}$ ,  $\mathcal{O}_{8L} = \frac{g_3}{16\pi^2}m_b\bar{s}\sigma^{\mu\nu}T^a b_R G_{\mu\nu}^a$ , and the last term consists of the four-quark operators. The SUSY contributions mainly affect the Wilson coefficients  $C_{7L,R}$  and  $C_{8L,R}$ . Each CP asymmetry depends on the coefficients differently.  $A_{\text{CP}}^{\text{dir}}(b \rightarrow s\gamma)$  is essentially determined by the imaginary parts of  $C_{7,8L}$ , because the

main contribution comes from the interference between  $\mathcal{O}_{7,8L}$  and the four-quark operator  $(\bar{s}\gamma^\mu c_L)(\bar{c}\gamma_\mu b_L)$ .  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow K_{\text{CP}}\gamma)$  is induced by the interference of  $\mathcal{O}_{7L}$  and  $\mathcal{O}_{7R}$  so that  $C_{7L}C_{7R}$  is relevant.  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow \phi K_S)$  is affected by  $C_{8L,R}$ . Also,  $|C_{7L}|^2 + |C_{7R}|^2$  is constrained by the experimental value of  $B(b \rightarrow s\gamma)$ .

In the mSUGRA, SUSY contributions to  $C_{7,8R}$  are very small. The deviation in the  $\arg C_{7L}$  is restricted by the EDM experiments. In the SU(5) SUSY GUT with  $\nu_R$ , the flavor mixing in the  $\tilde{d}_R$  sector is induced by the neutrino mixing and the GUT interactions [7]. Thus the SUSY contribution to  $C_{7R}$  can be large. The constraints on  $\arg C_{7L}$  is similar to the mSUGRA case. The allowed region in the non-degenerate case is much larger than that in the degenerate case since the  $\mu \rightarrow e\gamma$  constraint is less effective. In the U(2) model, large SUSY contributions are possible due to the flavor mixings and CP phases in the squark sector. SUSY contributions to  $C_{8L,R}$  are similar to  $C_{7L,R}$  in each model.

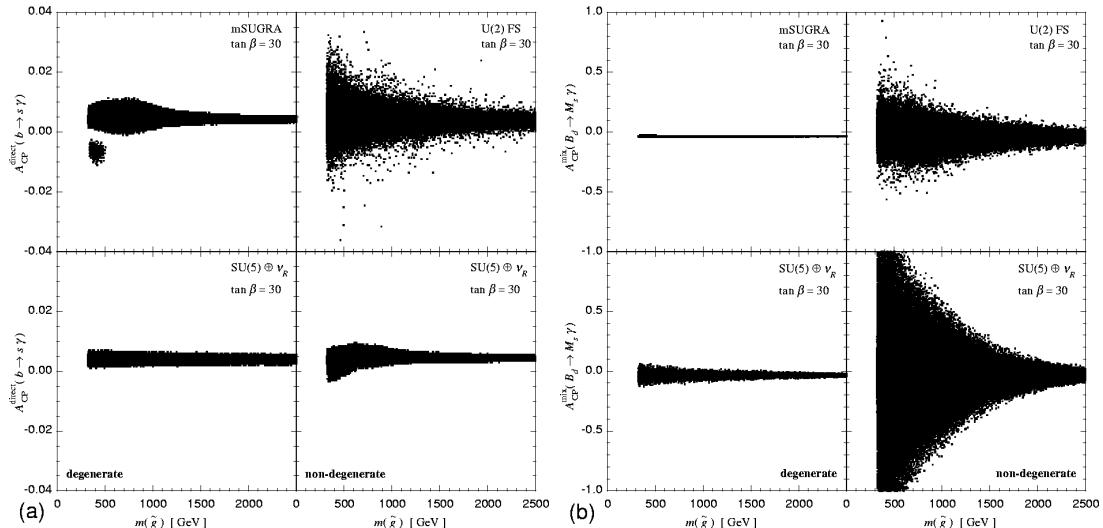


Figure 2: (a)  $A_{\text{CP}}^{\text{dir}}(b \rightarrow s\gamma)$ , and (b)  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow K_{\text{CP}}\gamma)$  as functions of the gluino mass.

In Fig. 2, we plot  $A_{\text{CP}}^{\text{dir}}(b \rightarrow s\gamma)$  and  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow K_{\text{CP}}\gamma)$  versus the gluino mass. Possible value of  $|A_{\text{CP}}^{\text{dir}}(b \rightarrow s\gamma)|$  is at most a few percent compared with the SM prediction  $\sim 0.5\%$ . The effect on  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow K_{\text{CP}}\gamma)$  is significant in the SU(5) SUSY GUT with  $\nu_R$  (non-degenerate case) and in the U(2) model due to the SUSY contribution to  $C_{7R}$ .

In Fig. 3, we show the correlation between  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow \phi K_S)$  and  $A_{\text{CP}}^{\text{mix}}(B_d \rightarrow J/\psi K_S)$  for the non-degenerate case of the SU(5) SUSY GUT with  $\nu_R$  and the U(2) model. In the SM, these asymmetries are the same. The SUSY effect on the  $B_d \rightarrow \phi K_S$  decay amplitude shows up as the deviation from the equality. In the non-degenerate case of the SU(5) SUSY GUT with  $\nu_R$ ,  $C_{8R}$  receives a large SUSY correction. On the other hand, in the U(2) model, both  $C_{8L}$  and  $C_{8R}$  are affected. For the other two cases, the deviations from the SM relation are small.

#### 4. Conclusion

In order to seek the possibility to distinguish SUSY models with  $B$  physics, we studied

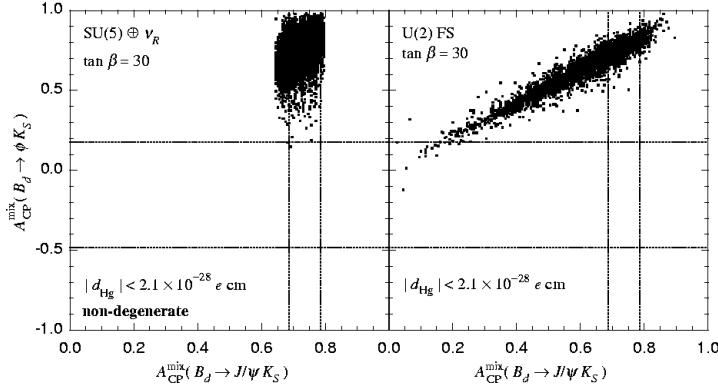


Figure 3: The correlation between  $A_{CP}^{\text{mix}}(B_d \rightarrow \phi K_S)$  and  $A_{CP}^{\text{mix}}(B_d \rightarrow J/\psi K_S)$ .

the unitarity triangle analysis and the  $b \rightarrow s$  decays. In the unitarity triangle analysis, we showed that each SUSY model provides the different pattern of the correlation among  $A_{CP}^{\text{mix}}(B_d \rightarrow J/\psi K_S)$ ,  $\Delta m_{B_s}$  and  $\phi_3$ , and could be distinguishable by precise measurements. We also explored SUSY effects on the CP asymmetries in  $b \rightarrow s\gamma$  and  $B_d \rightarrow \phi K_S$  decays. New signals in the mSUGRA and the degenerate case of the SU(5) SUSY GUT with  $\nu_R$  are relatively limited. The non-degenerate case of the SUSY GUT exhibits large deviations in  $A_{CP}^{\text{mix}}(B_d \rightarrow K_{CP}\gamma)$  and  $A_{CP}^{\text{mix}}(B_d \rightarrow \phi K_S)$ . The U(2) model predicts significant deviations in the  $b \rightarrow s$  decays as well as the unitarity triangle analysis.

Combining the above observation, we conclude that the study of the unitarity triangle and  $B$  decays could discriminate different SUSY flavor models. Since the flavor structure of the SUSY sector provides us a clue to the origin of the SUSY breaking and interactions at high energy scales,  $B$  physics will be essential to clarify the whole SUSY model.

## 5. Acknowledgements

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